4. CONCEPTUAL MODELS

Ten different methods of conceptualization, with their advantages and disadvantages, are presented in this chapter. A general recommendation as to which method to use is not given, as it is hardly possible. The problem, the ecosystem, the application of the model and the habits of the modeller will determine the preference of the conceptualization method.

A conceptual model has a function of its own. If flows and storages are given by numbers, the diagram gives an excellent survey of a steady state situation. It can be applied to get a picture of the changes in flows and storages if one or more forcing functions are changed and another steady state situation emerges. If first order reactions are assumed it is even easy to compute other steady state situations, which might prevail under other combinations of forcing functions, (see also chapter 5). Three illustrations and one example of this application of conceptual models are included in section 4.3 to give the reader an idea of these possibilities.

4. APPLICATION OF CONCEPTUAL MODELS.

Conceptualization is one of the early steps in the modelling procedure, see section 2.2, but it might also have a function of its own, as it will be illustrated in this chapter.

A conceptual model can be considered as a list of state variables and forcing functions of importance to the ecosystem and the problem in focus, but will also show how these components are connected by means of the processes. It is employed as a tool to create abstractions of reality in ecosystems and to delineate the level of organization that best meets the objectives of the model. A *wide spectrum* of conceptualization approaches is available and will be presented here. Some give only the components and the connections, other imply mathematical descriptions. It is hardly possible to give general recommendations as to which one to apply. It will be dependent on the problem, the ecosystem, the class of model and to a certain extent also on the habits of the modeller.

It is hardly possible to model without a conceptual diagram to visualize the modellers concepts of the system. The modeller will usually play with the idea of constructing various models of different complexity at this stage in the modelling procedure, making the first assumptions and selecting the complexity of the initial model or alternative models. It will require intuition to extract the applicable parts of the knowledge about the ecosystem and the problem involved. It is therefore not possible to give general lines on how a conceptual diagram is constructed, except that it is often better at this stage to use a slightly too complex model than a too simple approach. In the later stage of modelling it will be possible to exclude redundant components and processes. On the other hand it will make the modelling too cumbersome, if a too complex model is used even at this initial stage.

Generally, good knowledge about the system and the problem will facilitate the conceptualization step and increase the chance to find close to the right complexity for the initial model. The questions to be answered are: *What components and processes of the real system are essential to the model and the problem? Why? How?* In this process a suitable balance is sought between elegant simplicity and realistic detail.

Identification of the level of organization and selection of the needed complexity of the model are not trivial problems. Miller (1978) indicates 19 hierarchical levels in living systems, but to include all of them in an ecological model is of course an impossible task, mainly due to lack of data and general understanding of nature.

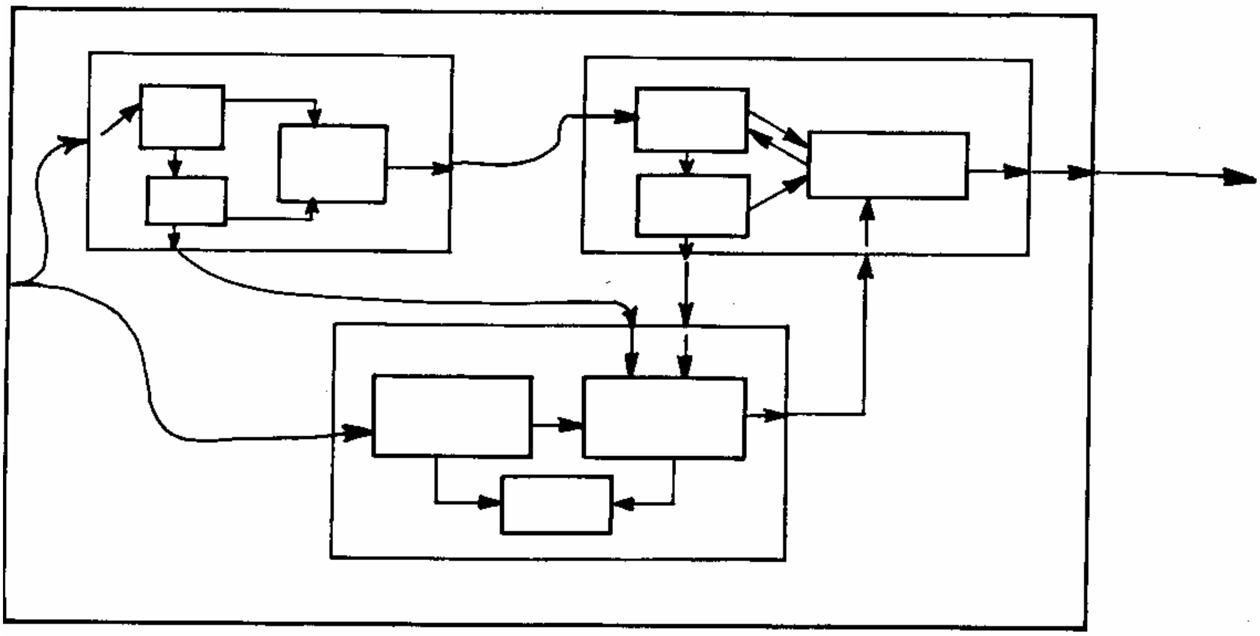

Fig.4.1: Conceptualization showing three levels of hierarchical organization.

It is, however, in most cases not necessary to include more *than a few or even only one hierarchical level* to understand a particular behaviour of an ecosystem at a particular level, see Pattee (1973), Weinberg (1975), Miller (1978) and Allen and Star (1982). Fig. 4.1 illustrates a model with three hierarchical levels, which might be needed if a multi goals model is constructed. The first level could f.inst. be a hydrological model, the next level a eutrophication model and the third level a model of phytoplankton growth, considering the intracellular nutrients concentrations.

Fig. 4.2 illustrates an actual case study, where the water quality of the Upper Nile Lake System has been constructed. The figure shows how models of the next hierarchical level are connected to form the total model.

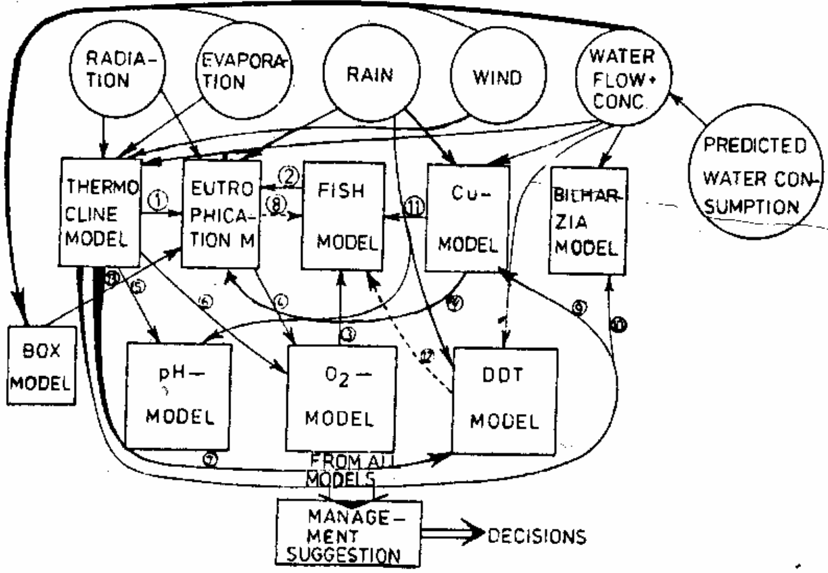

Fig.4.2: Connections of models to form a total model of the Upper Nile Lake System.

Each of the submodels shown has its own conceptual diagram, see f.inst. the conceptual diagram of the phosphorus flowing in a eutrophication model fig. 2.9. In this latter submodel there is a subsubmodel considering the above mentioned growth of phytoplankton by use of intracellular nutrients concentrations, which is conceptualized in fig. 4.3, symbols used in this figure, see fig. 4.4.

Models, which considers as well the distribution and effects of toxic substances, might often require three hierarchical levels: one for the hydrodynamics or aerodynamics to account for the distribution, one for the chemical and biochemical processes of the toxic substances in the environment and the third and last for the effect on the organism level.

4.2. TYPES OF CONCEPTUAL DIAGRAMS

Ten types of conceptual diagrams are presented and reviewed. Table 4.1 gives a summary of the characteristics of the various types of diagrams. In the table is also indicated, where each diagram example can be found with reference to a figure number.

Word models use a verbal description of model component and structure. Language is the tool of conceptualization in this case. Sentences can be used to describe a model briefly and precisely. However, word models of large complex ecosystems quickly become unwieldy and therefore they are only used for very simple models. The proverb "One picture is worth thousand words" explains, why the modeller needs to use other types of conceptual diagrams to visualize the model.

Picture models use components seen in nature and place them within a framework of spatial relationships. Fig. 7.16 shows such a picture model of a cypres dome. It indicates the components that must be included in the model. Another example is shown in fig. 4.5 taken from Seip (1983). The latter example illustrates the direction of interactions between the elements in a food web representation.

Box models are simple and commonly used conceptual design for ecosystem models. Each box represents a component in the model and arrows between boxes indicate processes. Fig. 2.8 shows an example of the P-flows in a eutrophication model. A similar diagram for the nitrogen flows is shown in fig. 2.1. The arrows indicate mass flows caused by processes. Fig. 4.6 gives a conceptual diagram of a global carbon model, used as basis for predictions of the climatic consequences of the increasing concentration of carbon dioxide in the atmosphere. The numbers in the boxes indicate the amount of carbon on a global basis, while the arrows give information on the amount of carbon transferred from one box to another per annum.

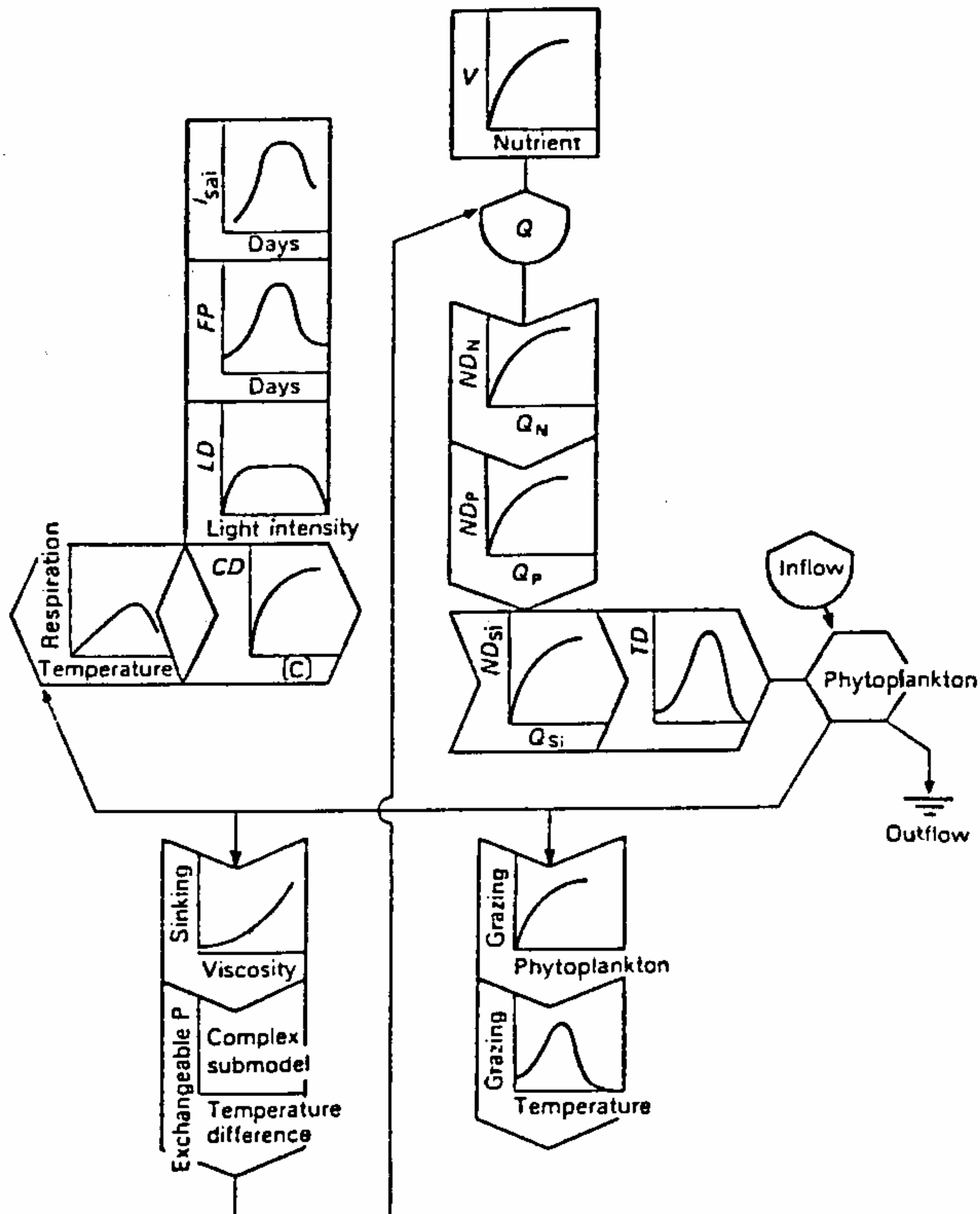

Fig.4.3: Flow chart of the phytoplankton model of Jørgensen (1976) and Jørgensen et al. (1978).

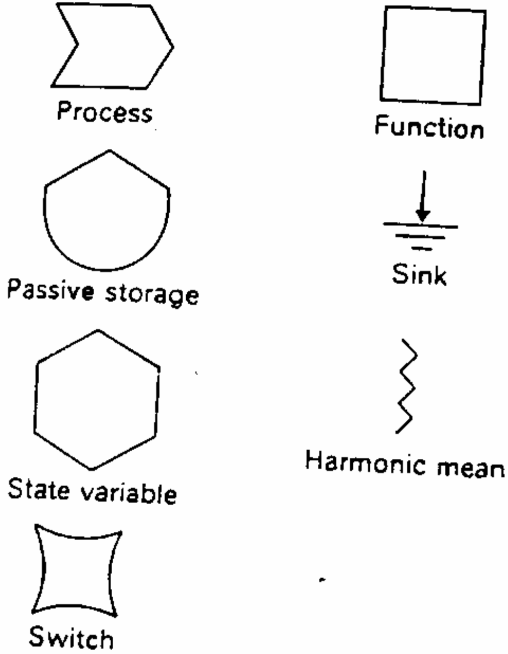

Fig.4.4: Symbols used in Fig. 4.3.

A model to predict the carbon dioxide concentration in the atmosphere can easily be developed on basis of the mass conservation principle by use of the numbers included in the diagram.

The term **black box models** is used, when the equations are set up on basis of an analysis of input and output relations f.inst. by statistical methods. The modeller is not concerned with the causality of these relations. Such a model might be very useful, provided that the input and output data are of sufficient quality. However, the model can only be applied on the case study, for which it has been developed.

New case studies will require new data, a new analysis of the data and consequently new relations.

White box models are constructed on the basis of causality for all processes. This does not imply that they can be applied on all similar case studies, because, as discussed in section 2.4, a model always reflects ecosystem characteristics. But in general a white box model will be applicable to other case studies with some modification.

In practice **most models are grey**, as they contain some causalities but also apply empirical expressions to account for some of the processes. Some modellers prefer other geometric shapes, for example, Wheeler et al. (1978) prefer circles to boxes in their conceptualization of a lead model. This leads to no principal difference in the construction and use of the diagram.

Input/output models differ only slightly from box models, as they can be considered as box models with indications of in- and outputs.The global carbon model,see fig.4.6 can be considered to be an input/output model as all in- and outputs of the boxes are indicated with numbers. Another example is shown in fig. 4.7. It is an oyster model, developed by Patten (1983).

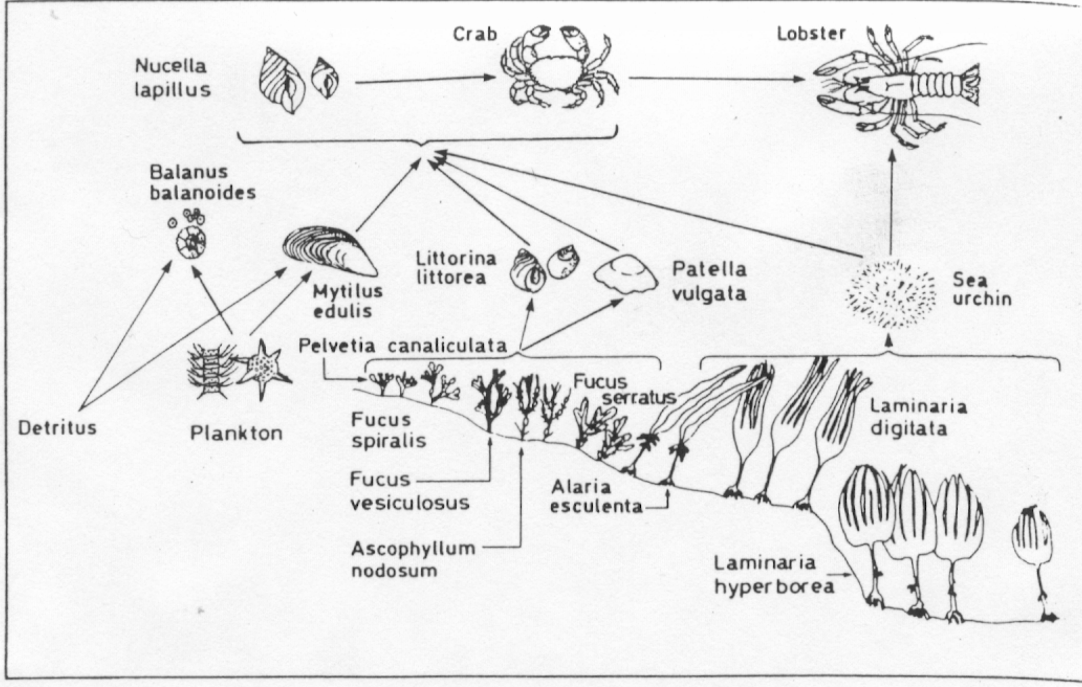

Fig.4.5: Generalized food webs of the Hardangerfjord rocky shores (reproduced from Seip 1983).

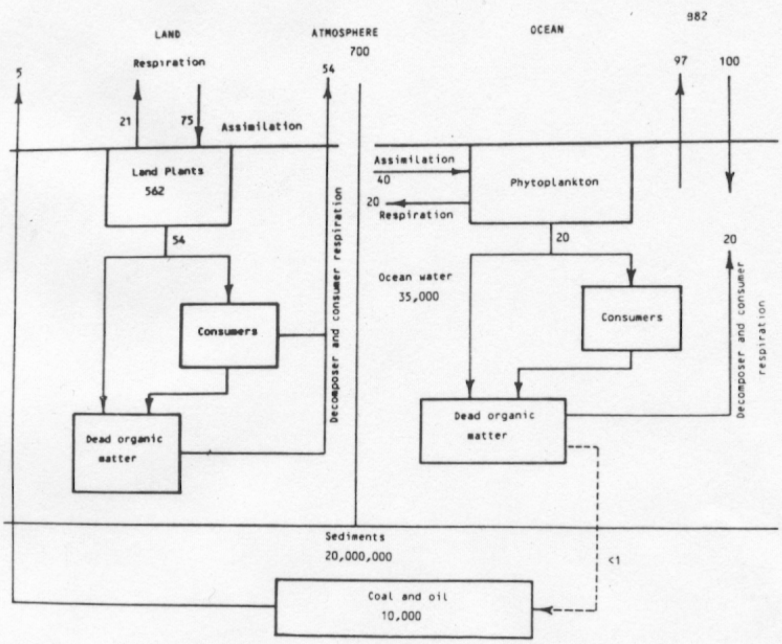

Fig.4.6: Carbon cycle, global. Values in compartments are in 10^{12} tons and in fluxes 10^{9} tons/year.

The same model is illustrated by use of **matrix conceptualization** in fig. 4.8. The first upper matrix is a so-called adjacency matrix, which indicates the connectivity of the system. This matrix has a_{ji} = 1 if a direct causal flow (or interaction) exists from compartment j (column) to compartment i (row), and a_{ji} = 0 otherwise. The lower matrix, called a flow or in/output matrix, represents the direct effects of compartment j on compartment i. The number expresses the probability that a substance in j will be transferred to i in one unit of time. P is a one step transition matrix in Marko chain theory and can be computed readily from storage and flow information. Notice that fig. 4.7 uses the units kcal/m² and kcal/m² day, while the flow matrix in fig. 4.8 uses six hours as unit. The number for a_{12} is therefore found as 15.7915/(4.2000) = 0.1974 10^{-2} indicated in the matrix as 1.974-3.

The two matrices provide a survey of the possible interactions and their quantative role.

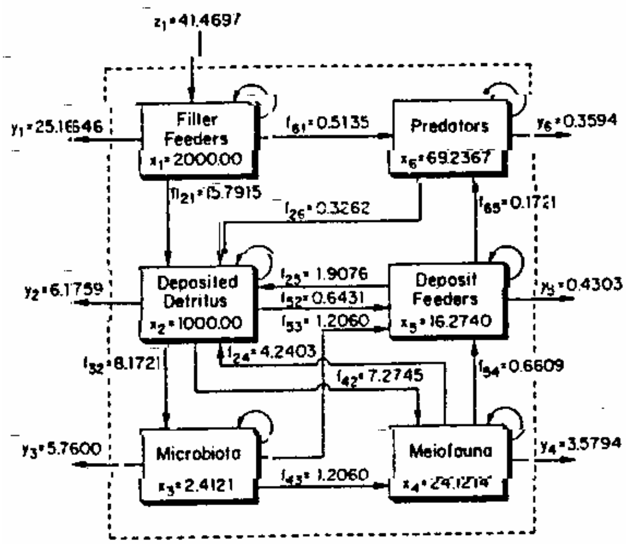

Fig. 4.7: Input/output model for energy flow (kcal $m^{-2}d^{-1}$) and storage (kcal m^{-2}) in an oyster reef community, (reproduced from Patten 1983).

The feedback dynamics diagrams use a symbolic language introduces by Forrester (1961), see fig. 4.9. Rectangles represent state variables. Parameters or constants are small cirles. Sinks and sources are cloudlike symbols, flows are arrows and rate equations are the pyramides that connect state variables to the flows.

A modification is developed by Park et al.(1979) see the symbols in fig. 4.4 and the phytoplankton model fig. 4.3, which uses these symbols. It differs from the Forrester diagrams mainly by giving more information on the processes, which are shown by a graphic representation.

A **computer flow chart** might be used as a conceptual model. The sequence of events shown in the flow chart can be considered a conceptualization of the ordering of important ecological processes. An example is given in fig. 4.10, which is a swamp model developed by Phipps (1979). The model subjects each of the three species in the swamp to the same sequence of events with specific parameters as function of species. Trees are born, grow and die off due to old age (KILL), lumbering (CUT) or environmental forces (FLOOD). Birth depends on al other processes. This type of model is very usefull in setting up computer programs, but does not give information on the interactions. F.inst. it is not possible to read on fig. 4.10 that GROW is a subroutine, which takes into account the interactions between water table and crowding on the individual tree species.

A subcategory of computer flow charts is analog computer diagrams. An example is shown in fig. 4.11. Analog symbols are used to represent storages and flows. An amplifier is used to sum and invert one or more inputs. By adding a capacitor to an amplifier we get an integrator. Analog computers have found only a limited use in ecological modelling. For descriptions see Patten (1971).

Compartments

(a)

to \ from	1	2	3	4	5	6	Row Sum
1	1	0	0	0	0	0	1
2	1	1	0	1	1	1	5
3	0	1	1	0	0	0	2
4	0	1	1	1	1	0	3
5	0	1	1	1	1	0	4
6	1	0	0	0	1	1	3
					3		

(b)

to \ from		2	3	4	5	6	Row Sum
	9.948-1	0	0	0	0	0	9.948-1
	1.974-3	9.944-1	0	4.395-2	2.930-2	1.178-3	1.071
	0	2.043-3	1.530-1	0	0	0	1.551-1
	0	1.818-3	1.250-1	9.121-0	0	0	1.039
	0	1.608-4	1.250-1	6.850-1	9.614-1	0	1.093
	6.419-5	0	0	0	2.644-3	8.975-1	1.000
Column Sum	9.969-1	9.985-1	4.030-1	9.629-1	9.934-1	9.987-1	5.353

Fig.4.8: Oyster reef model first order matrices (a) A for paths, and (b) P for causality. Example entry in P: 9.948-1 = 9.948×10^{-1}.

Signed digraph models extend the adjacency concept. Plus and minus signs are used to denote positive and negative interactions between the system components in the matrix and the same information is given a box diagram, see fig. 4.12, where a general benthic model is shown (Puccia, 1983). Lines connecting the components represent the causal effects. Positive effects are indicated with arrows and lines with a small circle head indicate a negative effect.

Energy circuit diagrams, developed by Odum (see Odum 1971, 1972 and 1983) are designed to give information on thermodynamic constraints, feed-back mechanisms and energy flows. The most commonly used symbols in this language are shown fig. 4.13. As the symbols have an implicit mathematical meaning, it gives many informations about the mathematics of the model. It is, furthermore, rich in conceptual information and hierarchical levels can easily be displayed, as demonstrated in fig. 4.14 and 8.9. Numerous other examples can be found in the literature, see f.inst. Odum (1983). A review of these examples will reveal, that energy circuit diagrams are very informative, but they are difficult to read and survey, when the models are a little more complicated.

TABLE 4.1

Types of conceptual Diagrams

Conceptual design	Characteristics, advantages and disadvantages	Example see figure
Word models	Sentences describe model Simple to use. Cannot be used for complex models.	
Picture models	Picture of ecosystem components Very illustrative. Difficult to transfer to mathematical formulation.	Figs. 4.5 and 7.16
Box models equations	Components are boxes, processes are arrows, simple to use. Relatively easy to transfer to mathematical-formulation, but give little information on process equations	Fig. 2.1, 2.8 and 4.6
Black box models	Based upon statistical analysis. Relate input and output without causality	
Input/output models	Box models with indication of input and output as rates. Assume often linearity and lack temporal dynamics.	Fig. 4.6 and 4.7
Matrix model	Matrix notation used to indicate connectivity and flow rates. Assume linearity and lack temporal dynamics.	Fig. 4.8
Forrester diagrams (with modifications)	Include feed-backs. Give more information by use of symbolic language.	Fig. 4.3, 4.4 and 4.9
Computer flow charts	Easy to set up computer program. Difficult to give information on processes and interactions.	Fig. 4.10 and 4.11
Signed digraph models	Contain logic gates and qualitative interactions. Matrix notation easy to use. Assume linearity and lack temporal dynamics.	Fig.4.12
Energy circuit diagrams	Give detailed information on thermodynamic constraints. Feed-back mechanisms and energy flow. Relatively difficult to survey.	Fig. 4.14 and 8.9

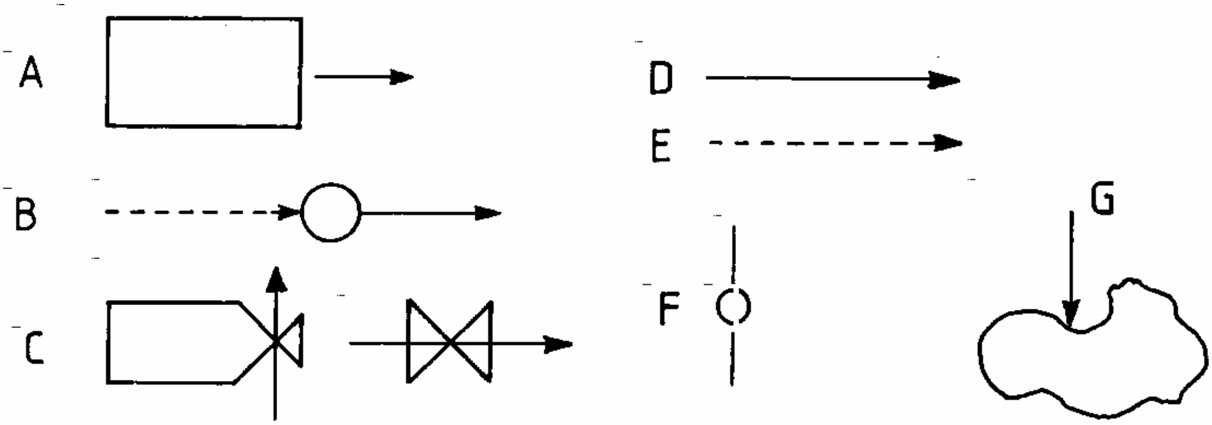

Fig.4.9: Symbolic language introduced by Forrester (Jeffers, 1978). A state variable, B Auxiliary variable, C Rate equations. D Mass flow, E Information, F Parameter. G Sink.

4.3. THE CONCEPTUAL DIAGRAM AS MODELLING TOOL

The Word models, Picture models and Box models give all a description of the relation between the problem and the ecosystem. They are very useful as a first step in modelling, but their application as a modelling tool of its own is rather limited. Additional information is needed to be able to answer even semiquantitative questions. It is, however, possible by use of many of the other conceptual approaches, which will be demonstrated in this paragraph.